ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

Latte Art Coffee Machine

Team #10

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Abstract

This report summarizes the design of an autonomous latte art coffee machine that converts a user-uploaded image into a printable path and draws it on a beverage surface. The system combines a CoreXY X–Y platform, a syringe-based dispensing head, image processing, route planning, GRBL motion control, and a browser interface. The design goal is to provide a compact and repeatable workflow from digital image input to physical latte-art output. This shortened report focuses on the final architecture, verification plan, tolerance issues, cost, safety, and future improvements.

Contents

1 Introduction

Latte art normally depends on a barista's hand motion, pouring speed, and timing. Repeating the same design is difficult, especially when the target pattern comes from a digital image. This project addresses that problem by building a mechatronic machine that accepts an image, generates a drawing path, and deposits patterning liquid above a fixed cup.

1.1 Problem Statement

The main engineering challenge is the integration of three functions: converting images into printable trajectories, moving a nozzle accurately over a cup, and dispensing a stable amount of material at the correct time. The system must also be simple enough for demonstration use and safe around moving hardware, electronics, and hot beverages.

1.2 Solution Overview

The workflow is shown in Figure 1. A user uploads an image through a browser page. The backend normalizes the image, extracts contours, creates ordered route commands, and sends the resulting motion path to a GRBL-based controller. The controller drives a CoreXY X–Y platform and a syringe plunger so that the nozzle can draw the pattern on the beverage surface.

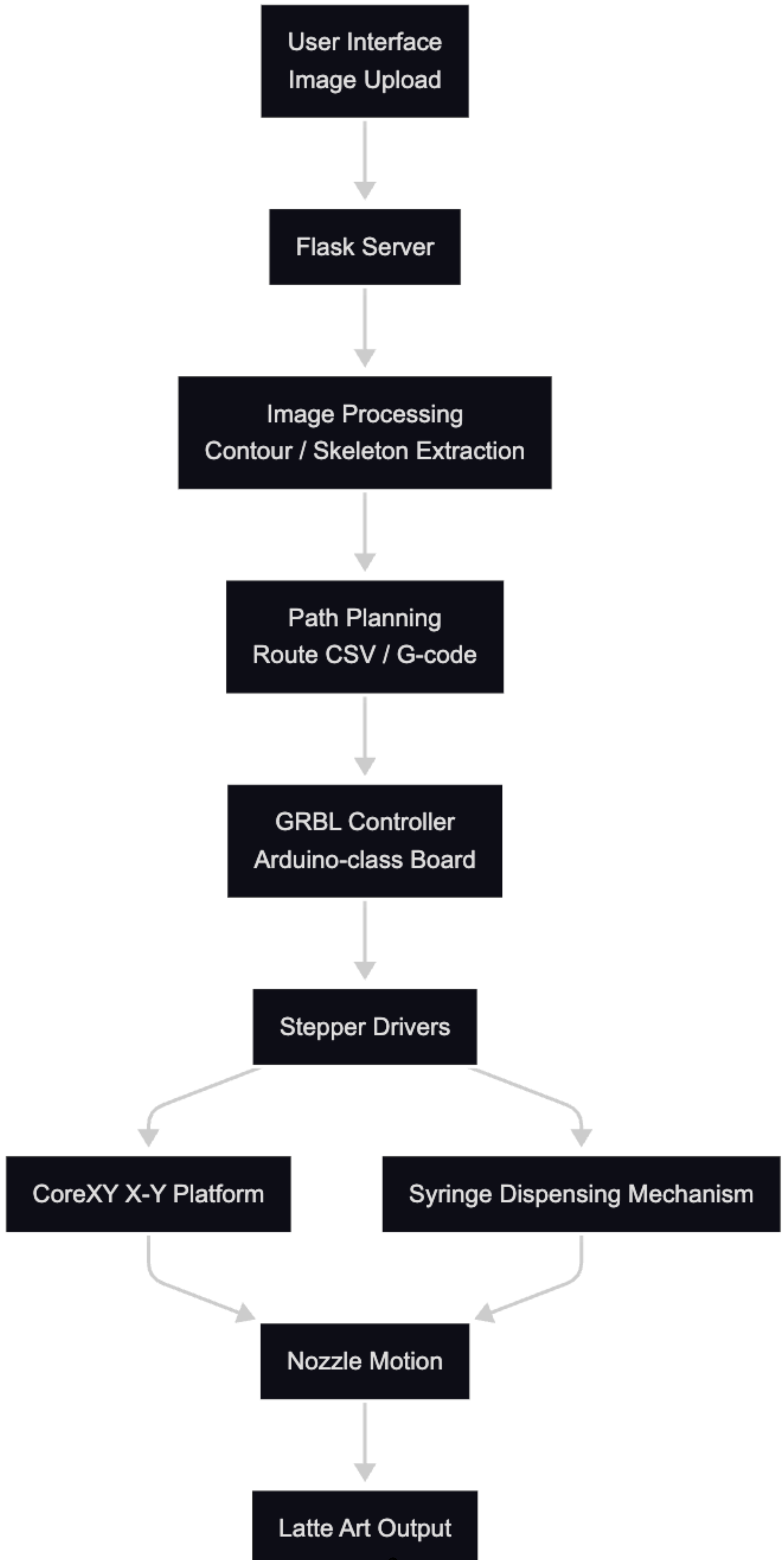

Figure 1: Digital-to-physical workflow of the autonomous latte art machine.

1.3 High-Level Requirements

The system requirements are grouped into six categories: fixed cup alignment, reliable image-to-path conversion, repeatable X–Y motion, stable dispensing, simple user operation, and safe behavior during faults or manual stopping. These categories guide the design and the verification plan in later sections.

2 System Design and Hardware

The hardware consists of a CoreXY X–Y platform, a syringe dispensing head, motor power electronics, and a controller stack. The updated mechanical structure uses an aluminum-extrusion frame, fixed stepper-motor locations, belt-driven planar motion, and a moving gantry that carries the tool fixture.

2.1 CoreXY X–Y Platform

The X–Y platform uses a CoreXY layout. Two frame-mounted stepper motors drive coupled belts so the nozzle carriage can move in the horizontal plane while the motors remain stationary. This reduces moving mass and helps limit vibration during sharp turns, which is important for drawing on a liquid surface [1].

Figure 2 shows the main frame and belt path. The cup stays fixed below the printable region while the nozzle follows the planned route. The carriage should hold the nozzle close to the gantry centerline to reduce cantilever loading and preserve positional stability.

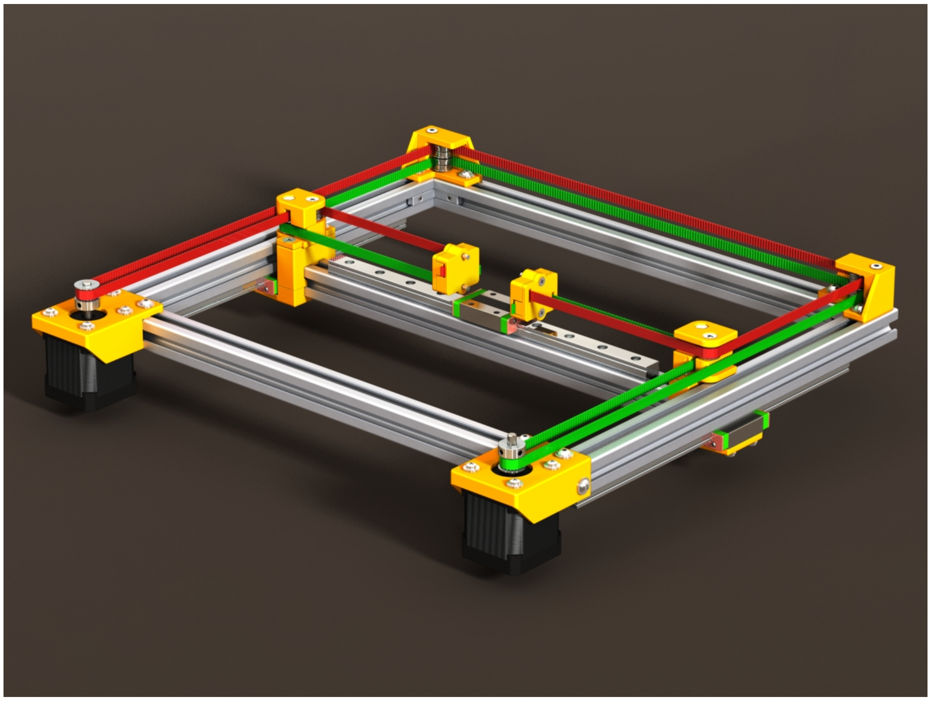

Figure 2: Rendered overview of the updated CoreXY X–Y platform.

Figure 3 shows the carriage area where the rail, bracket, and tool fixture meet. This region is the main mechanical interface for the dispensing head, so alignment and stiffness here directly affect nozzle accuracy.

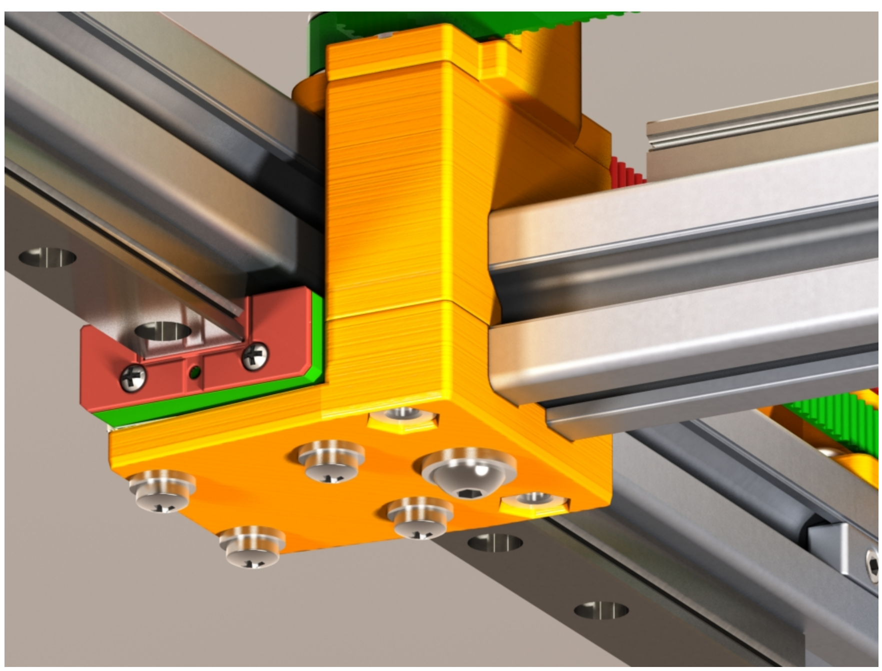

Figure 3: Close-up rendering of the CoreXY rail and carriage interface.

Figure 4 records the key frame relationships supplied with the mechanical drawing:

$$X = \text{XML} + 73\,\text{mm}, \qquad \text{FRAME-X} = X + 7\,\text{mm}, \qquad \text{FRAME-Y} = \text{YML} + 56\,\text{mm}.$$

These dimensions help scale the printable area while keeping clearance for the cup, belt routing, and motor mounts.

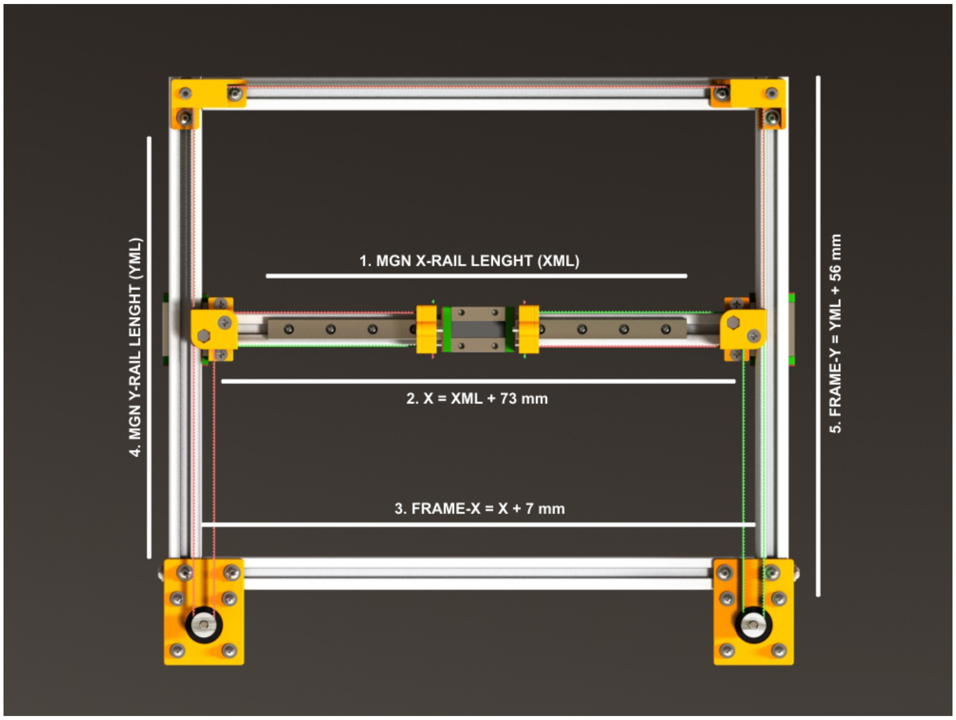

Figure 4: Dimensioned CoreXY layout used for frame sizing.

2.2 Dispensing Mechanism

The dispensing subsystem uses a syringe/plunger concept driven by a stepper motor through a linear mechanism. This makes output volume depend on commanded plunger displacement and allows dispensing to be synchronized with X–Y motion. The design supports both short pulse deposition at fixed points and continuous deposition along route segments. The most important goals are quick start/stop response, repeatable material release, limited dripping, and a lightweight head.

2.3 Power and Controller Electronics

Stepper drivers use a dedicated 12 V motor-power path, while the microcontroller and communication interface operate on logic-level power. Separating these paths reduces electrical noise and improves reliability near the fluid system. Wiring should be insulated, strain-relieved, and routed away from spill zones.

The controller is an Arduino-class board running GRBL firmware [2], [3]. It receives G-code from the host computer and produces coordinated step pulses for the two CoreXY motors and the syringe axis. This CNC-style interface creates a clean boundary between image-processing software and low-level motion execution.

3 Software

3.1 User Interface and Server

The machine is operated through a browser interface. The user uploads a PNG image, starts the job, and receives a preview while the physical drawing process runs. The page is intentionally simple so that the demonstration workflow is clear: upload, preview, and print.

The web service is implemented with Flask [4]. It validates the upload, creates a job directory, runs the image-processing pipeline, checks that route and preview files were generated, and starts the GRBL drawing script. Lightweight status endpoints allow the interface to report whether the machine is idle, processing, drawing, or in an error state. For remote demonstrations, a tunnel such as frp can forward the local service while the serial connection remains attached to the local computer [5].

3.2 Backend Processing Pipeline

The backend converts a raster image into route commands through five stages:

1. normalize the image into a fixed canvas;
2. extract major contours with grayscale conversion, blur, and Canny edge detection;
3. convert the line image into skeleton paths;
4. order the paths into a route CSV with `MOVE` and `DRAW` events;
5. stream GRBL-compatible G-code to the controller.

The route CSV is the key interchange file. It is used both for preview rendering and for physical execution, which keeps the displayed plan consistent with the machine command sequence.

3.3 Motion and Dispensing Control

Travel moves are issued as rapid X–Y movements. Drawing moves use coordinated linear commands with X–Y position, feed rate, and syringe-axis increments. The software can reduce speed near sharp corners and stroke endpoints to avoid vibration and surface disturbance. The syringe increment for each stroke can also be scaled by stroke length or drawing-point count so that short features receive less material and long features receive more.

Because the machine is a single physical resource, the backend uses a job lock to prevent overlapping submissions. While a job is active, later requests receive a busy response instead of entering an uncontrolled queue. This protects the hardware and makes user feedback more predictable.

4 Requirements and Verification

The original design requirements cover the motion platform, dispensing head, control stack, and interface. Table 1 summarizes the most important quantitative targets.

Table 1: Key quantitative requirements.

Subsystem	Representative requirements
CoreXY platform	Printable area at least 120 mm × 120 mm; positioning accuracy within ±1.0 mm; repeatability within ±0.5 mm; speed at least 40 mm/s; target reach time no more than 3 s.
Dispensing head	Volume variation no more than ±10%; start/stop response no more than 0.2 s; stop within 0.3 s; dot diameter between 2 mm and 5 mm; nozzle distance 10 ± 3 mm.
Control system	Image conversion within 10 s; route coverage at least 95%; timing error within ±0.1 s; missed dispensing points no more than 1%; job completion within 120 s.
User interface	Accept common image uploads below 10 MB; start printing within three interaction steps; invalid-upload notice within 2 s; manual stop command within 1 s.

4.1 Verification Strategy

No final numerical test data were included with the source materials, so this section is written as a verification plan rather than a measured-results claim. The plan connects each requirement to a practical test and acceptance basis.

Table 2: Condensed verification plan.

Subsystem	Test method	Acceptance basis
CoreXY platform	Command a calibrated grid, measure actual nozzle position, and repeat selected points.	Compare error, repeatability, speed, and overshoot with target limits.
Dispensing head	Run repeated pulse and route-segment tests; measure feature size, delay, and residual flow.	Check volume consistency, dot size, response time, dripping, and clogging behavior.
Control system	Submit simple, dense, and invalid images; record conversion time, route coverage, and stop response.	Confirm timing, route completeness, synchronization, and fault response.
Interface	Test upload, preview, busy-state, invalid-file, and stop-button behavior.	Confirm understandable operation, prompt feedback, and safe cancellation.

Grid tests reveal mechanical scale error and local distortion. Dispensing tests should first isolate the plunger mechanism, then repeat the same checks while the X–Y carriage is moving. Software tests should include both clean geometric images and noisy images so that route quality and error handling can be evaluated.

5 Tolerance Analysis

The three most important tolerance concerns are nozzle height, planar path error, and vibration of the liquid surface.

5.1 Nozzle-to-Surface Distance

The design target for nozzle clearance is 10 ± 3 mm. Too little clearance risks collision with the cup or foam, while excessive clearance can broaden the deposited line before it reaches the surface.

A repeatable cup holder and a simple height-calibration step are therefore as important as motor resolution.

5.2 Motion and Dispensing Error

CoreXY belt tension, rail alignment, pulley quality, and motor step accuracy all affect X–Y position. The syringe axis also introduces error because delayed start or residual flow can overfill endpoints or connect nearby strokes. The design mitigates these risks by keeping motor mass fixed, using coordinated GRBL motion, reducing speed near corners, and minimizing unnecessary travel between components.

5.3 Liquid-Surface Disturbance

Sharp accelerations can shake the frame and disturb the beverage surface. The planned path may be accurate while the liquid surface moves underneath the nozzle. Conservative feed rates, acceleration limits, smooth cornering, and a rigid frame are therefore required for recognizable output.

6 Cost and Schedule

6.1 Estimated Cost

Table 3 updates the project cost using the cost file provided with this revision. The total estimated prototype cost is 870.76 RMB. Small consumables such as tape, extra wires, spare connectors, and cleaning supplies are not included.

Table 3: Updated prototype cost based on the supplied cost list.

Item	Price (RMB)
Syringes (10 pcs)	29.90
Stepper motors (2 pcs)	260.00
Aluminum frame	107.50
3D printing material	304.48
Chocolate sauce	28.98
Foaming liquid	9.90
Milk	50.00
Coffee	25.00
Coffee cups	15.00
12 V power adapter	40.00
Estimated subtotal	**870.76**

6.2 Project Schedule

The project schedule moved from component selection and subsystem design to assembly, calibration, integration, and final presentation. The main workflow was: select and order components, design and build the frame, assemble the dispensing mechanism, develop image processing and motion control, integrate hardware and software, tune the machine, and prepare the final demonstration and report.

7 Ethics and Safety

7.1 Ethics

The machine converts user-provided images into physical patterns. Uploaded files should not be stored longer than needed for the drawing job, and users should be told that output quality depends on image clarity, machine calibration, and fluid behavior. Public demonstrations should also discourage offensive or inappropriate images. External motion-control, web-server, and open-source software tools should be credited properly.

7.2 Safety

The device combines moving belts, electronics, and hot beverages. Key safety controls include shielding or controlled access around moving parts, a stable cup holder, insulated and strain-relieved wiring, careful separation of liquid and power electronics, and a reliable stop procedure. The frame should remain rigid during repeated motion so that belt derailing, loose fasteners, or sudden carriage movement do not create hazards.

8 Improvements and Future Work

Future work should focus on three areas. First, the image-processing pipeline can be improved with adaptive thresholds, contrast enhancement, and subject segmentation so that complex or low-contrast images produce cleaner paths. Second, the dispensing system can be refined with start/stop compensation, better nozzle geometry, and calibration models that reduce residual dripping. Third, setup can be simplified through automatic serial-port discovery, a work-area calibration wizard, and a local status panel with stop, reset, and progress information.

References

[1] CoreXY, *Corexy motion system*, 2025. Accessed: May 16, 2026. [Online]. Available: https://corexy.com/.

[2] Arduino, *Arduino documentation*, 2025. Accessed: May 16, 2026. [Online]. Available: https://docs.arduino.cc/.

[3] S. Jeon, *GRBL: An open source, embedded, high performance g-code parser and cnc milling controller*, 2025. Accessed: May 16, 2026. [Online]. Available: https://github.com/grbl/grbl.

[4] Pallets, *Flask documentation*, 2025. Accessed: May 16, 2026. [Online]. Available: https://flask.palletsprojects.com/.

[5] fatedier, *Fast reverse proxy (frp)*, 2025. Accessed: May 16, 2026. [Online]. Available: https://github.com/fatedier/frp.

A Supporting Design Materials

The source package includes the CoreXY overview, carriage-detail rendering, dimensioned platform drawing, requirement tables, and updated cost table. These materials support the shortened report while keeping the main body concise.