

ECE 445 · SENIOR DESIGN · SPRING 2026 · GROUP 42

Autonomous Cold Salad Bar

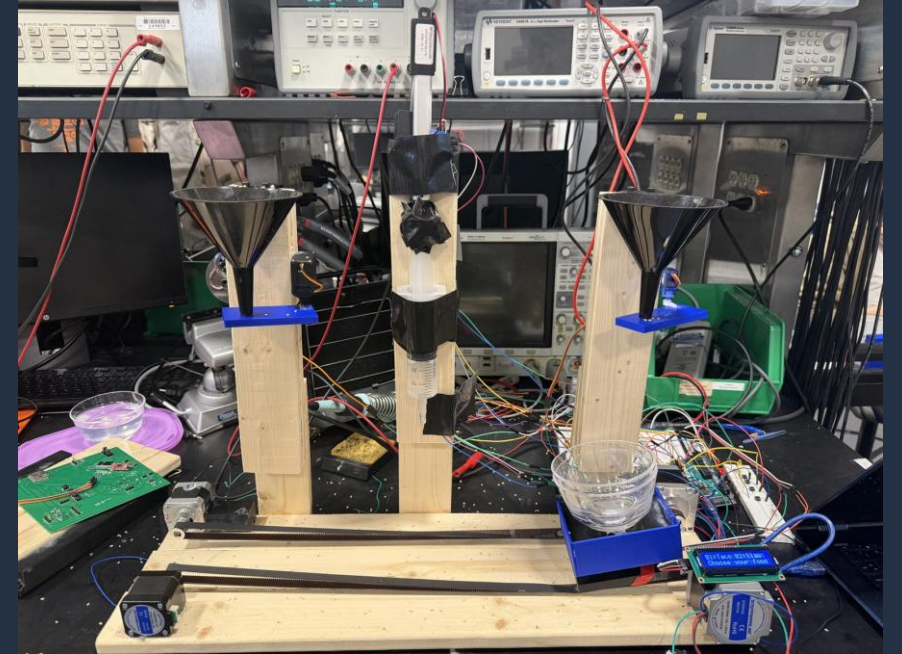
Final presentation · Spring 2026

TEAM MEMBERS

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As-built system: three dispensing stations on a stepper-driven conveyor

PROJECT PURPOSE

What this project is meant to do

MISSION

Increase the accuracy, speed, and consistency of food dispensing in assembly-line fast-food services (Chipotle, Qdoba, Forage Kitchen) by replacing manual scooping with automated portioning.



More accurate

Load-cell feedback hits every portion to ± 5 g. No over-scooping, no under-serving.



Faster service

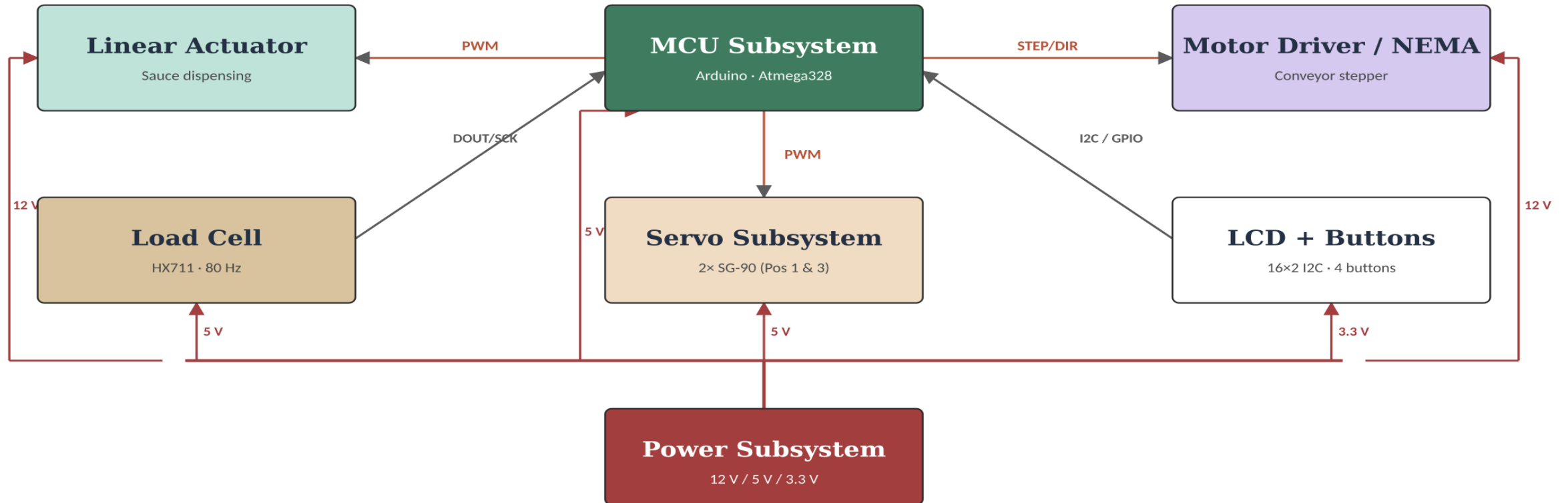
Full bowl assembled consistently during peak hours when human error climbs.



Better workers

Frees staff from repetitive scooping to focus on quality control and customer interaction.

Block diagram (as built)



What changed since proposal

BEFORE

ST7789 240×240 SPI display, 3 buttons

→ AFTER

16×2 I²C LCD, 4 buttons

16×2 LCD covers the entire menu in two lines and frees up GPIO. Added a 4th button to expose admin actions (tare, manual refill).

BEFORE

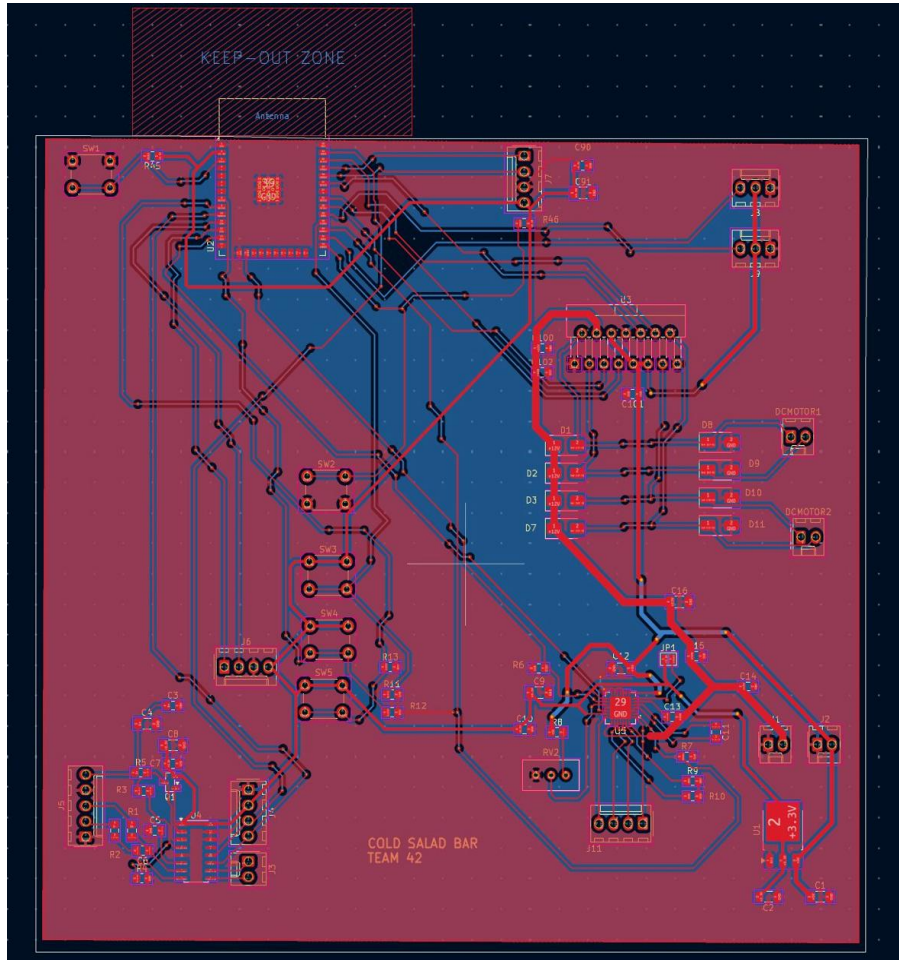
5 mm anti-drip retraction

→ AFTER

Volumetric closed-loop dispense

Drip mitigation alone wasn't enough. Replaced fixed 5 mm retract with a weight-targeted loop: push 1 s, weigh, repeat until ≥ 5 g. Same result with no manual tuning.

Designing & fabricating the PCB



KiCad layout

- 1 MCU & breakout**
ESP32-S3 footprint with USB-UART pads.
- 2 Motor drivers**
Stepper driver (TMC2209-style) and DC H-bridge for the linear actuator share the 12 V rail.
- 3 HX711 front-end**
Remake of breakout board.
- 4 Power**
12 V input → buck to 5 V (logic, servos) and LDO to 3.3 V (LCD, sensor I/O).
- 5 Connectors**
Connectors for stepper, actuator, and load cell subsystems.

Mechanical fabrication



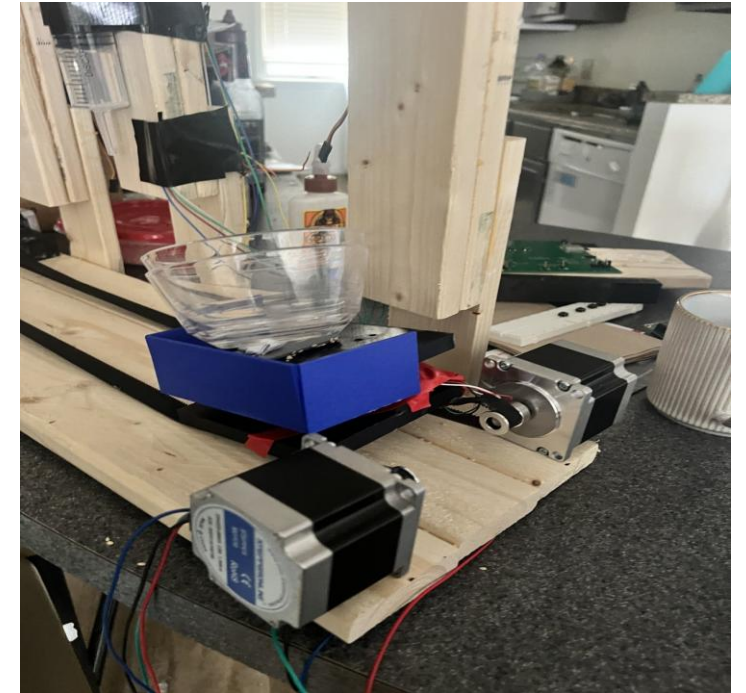
Solid-food station

Funnel + SG-90 servo gate. Sweep open 30° → hold 0.5 s → close. Pulse repeats until the load cell registers +10 g.



Liquid station

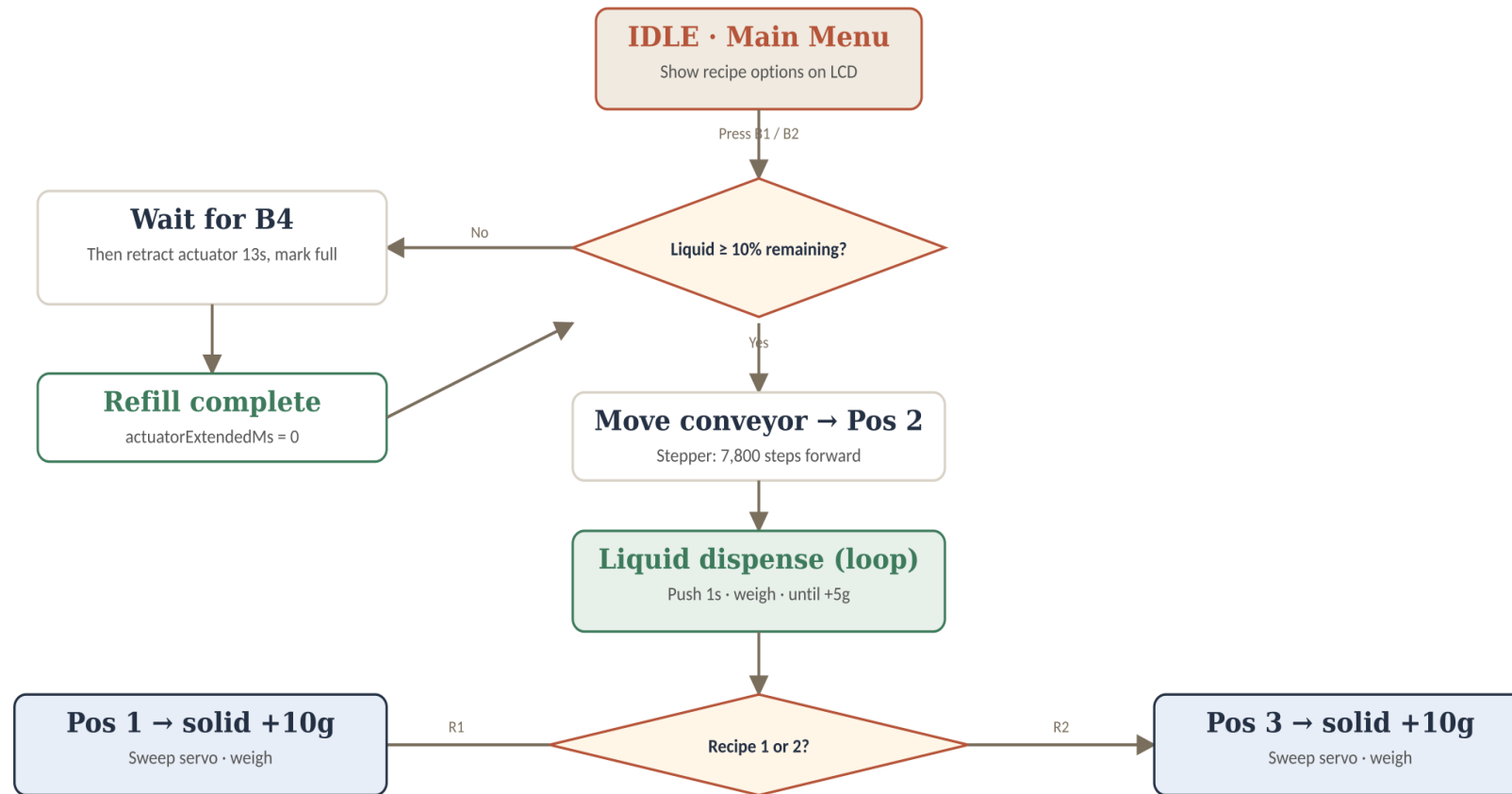
60 mL syringe driven by a 12 V linear actuator through an H-bridge. ~14 s full-stroke gives ~50 mL of dispensable sauce.



Conveyor & bowl

Belt-driven sled moves the bowl between three positions on a NEMA-17 stepper. ~7,800 steps per station gap.

Dispensing state machine



After both solid stations: show "Food ready" 30 s, return to Pos 1, back to IDLE

KEY DESIGN POINTS

Closed-loop dispense

Every station weighs the bowl directly. No timing-based volume estimates, the firmware doesn't stop until the target mass is hit.

Liquid pre-check

Before each recipe, firmware checks cumulative actuator extension against a 10 % safety margin. Below threshold → block until B4 refill.

Falling-edge buttons

All four buttons use INPUT_PULLUP and edge detection so a long press counts as one event.

Per-recipe ordering

Recipe 1: Pos 2 → Pos 1 → Pos 3.

Recipe 2: Pos 2 → Pos 3 → Pos 1.

Last position is the pickup point, no return move needed.

Load cell: mass accuracy

REQUIREMENT

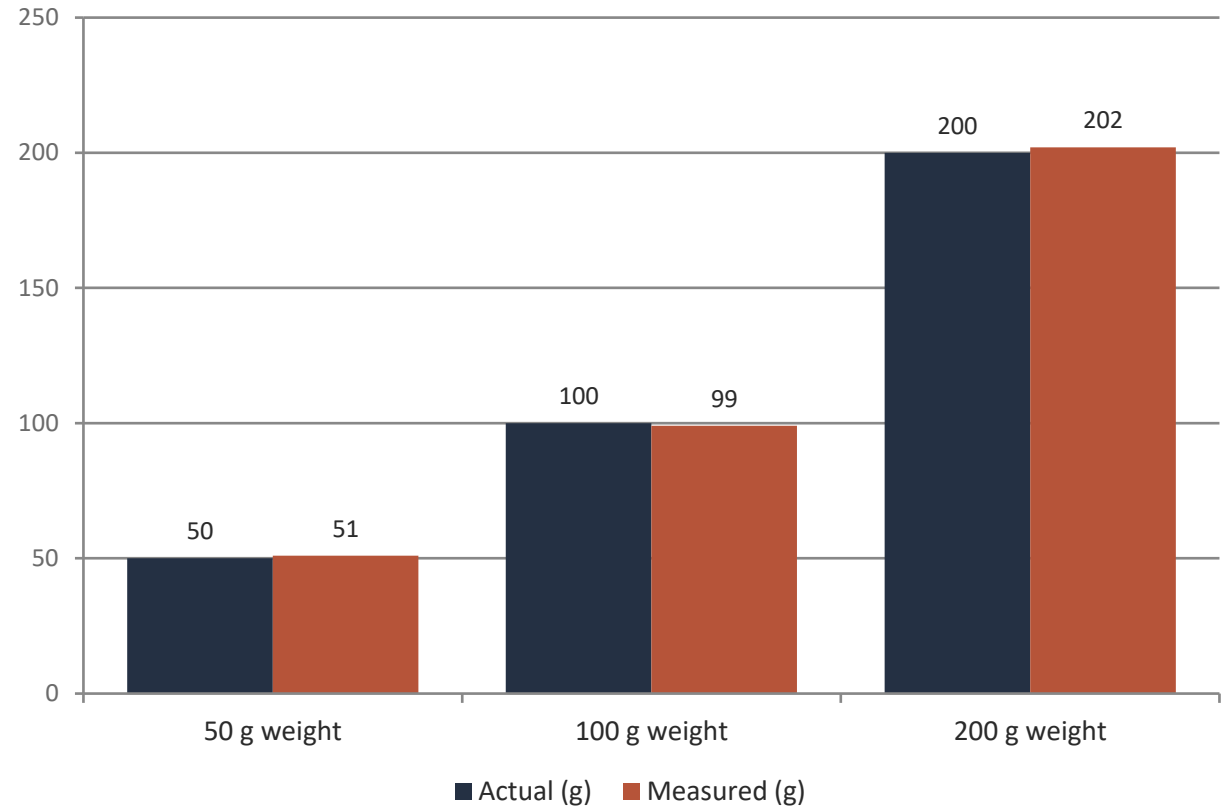
Mass measurement accuracy must be ± 5 g for loads between 0–1000 g.

VERIFICATION

Test with calibrated 50 g, 100 g, and 200 g weights. Zero-scale the load cell, place each weight on the bowl plate, and record the steady-state reading. All outputs must be within ± 5 g of the known mass.

PASS ± 5 g TOLERANCE MET

Measured vs actual across calibrated weights



Max deviation: 2.3 g · all within ± 5 g

Load cell: repeatability

REQUIREMENT

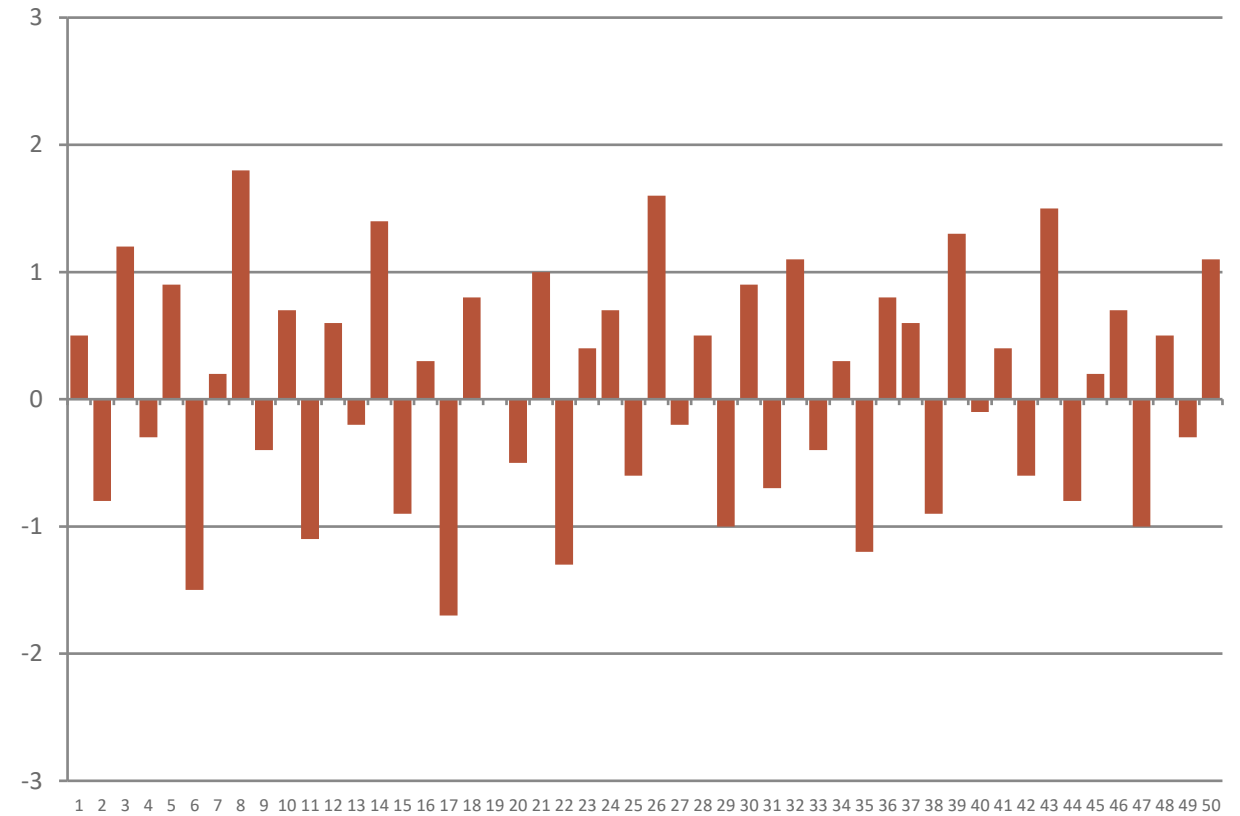
Standard deviation of dispensed mass must not exceed 1.5 g over 50 consecutive cycles.

VERIFICATION

Dispense 50 identical 50 g servings back-to-back, record each actual weight on an external reference scale, and compute the standard deviation of the residuals. Must be ≤ 1.5 g.

PASS $\sigma = 1.08$ g ≤ 1.5 g

Per-cycle deviation from 50 g target (50 cycles)



$\sigma = 1.08$ g · $\max |\Delta| = 1.8$ g · all cycles within ± 2 g

Liquid dispense accuracy

REQUIREMENT

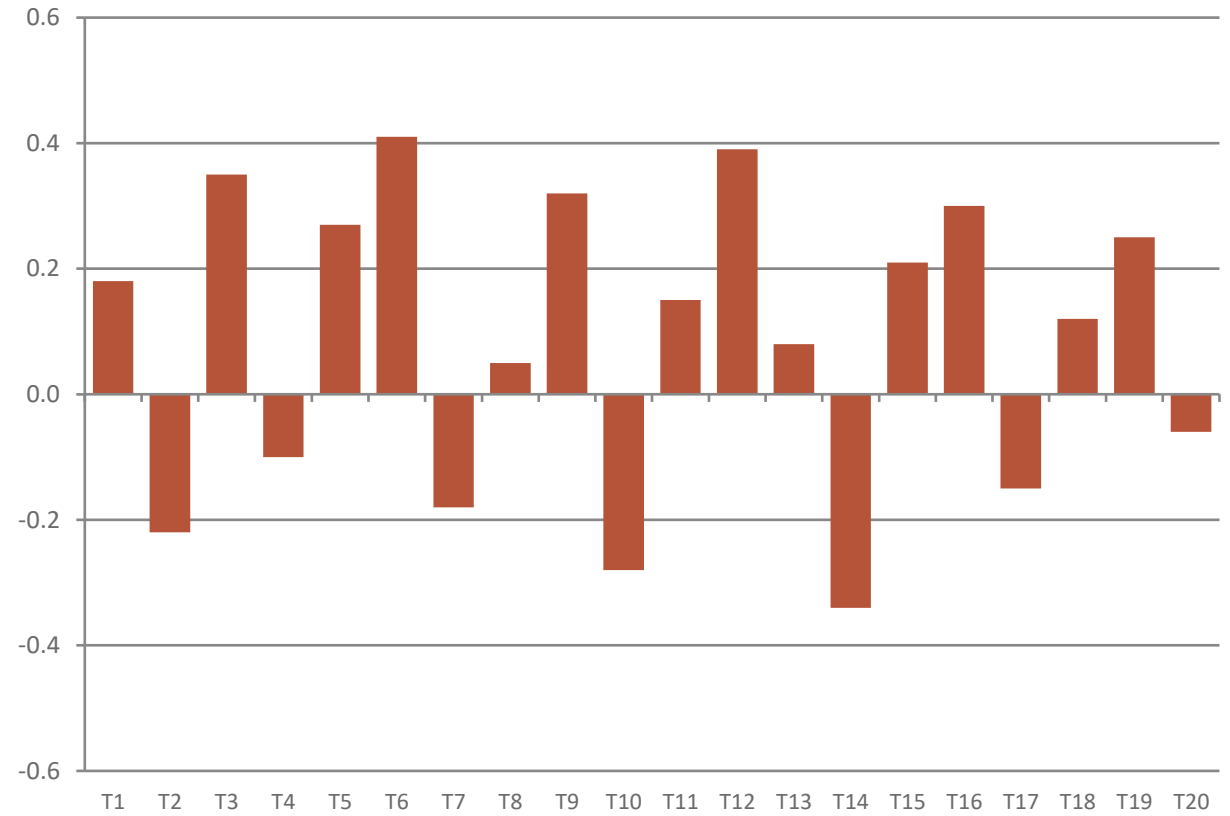
Liquid dispense (5 g target) must complete within ± 0.5 g over 20 trials, with zero post-stop drip exceeding 0.5 g.

VERIFICATION

Run the dispense loop 20 times against a 5 g target. After each trial, log actual dispensed mass and collect any post-stop drip on a secondary scale for 5 s. All trials must satisfy $|\Delta| \leq 0.5$ g and drip ≤ 0.5 g.

PASS $\max |\Delta| = 0.41 \text{ g} < 0.5 \text{ g}$

Dispense error vs 5 g target (20 trials)



Mean $|\Delta| = 0.21 \text{ g}$ · max $|\Delta| = 0.41 \text{ g}$ · 0 / 20 trials exceed limit

Conveyor: positioning accuracy

REQUIREMENT

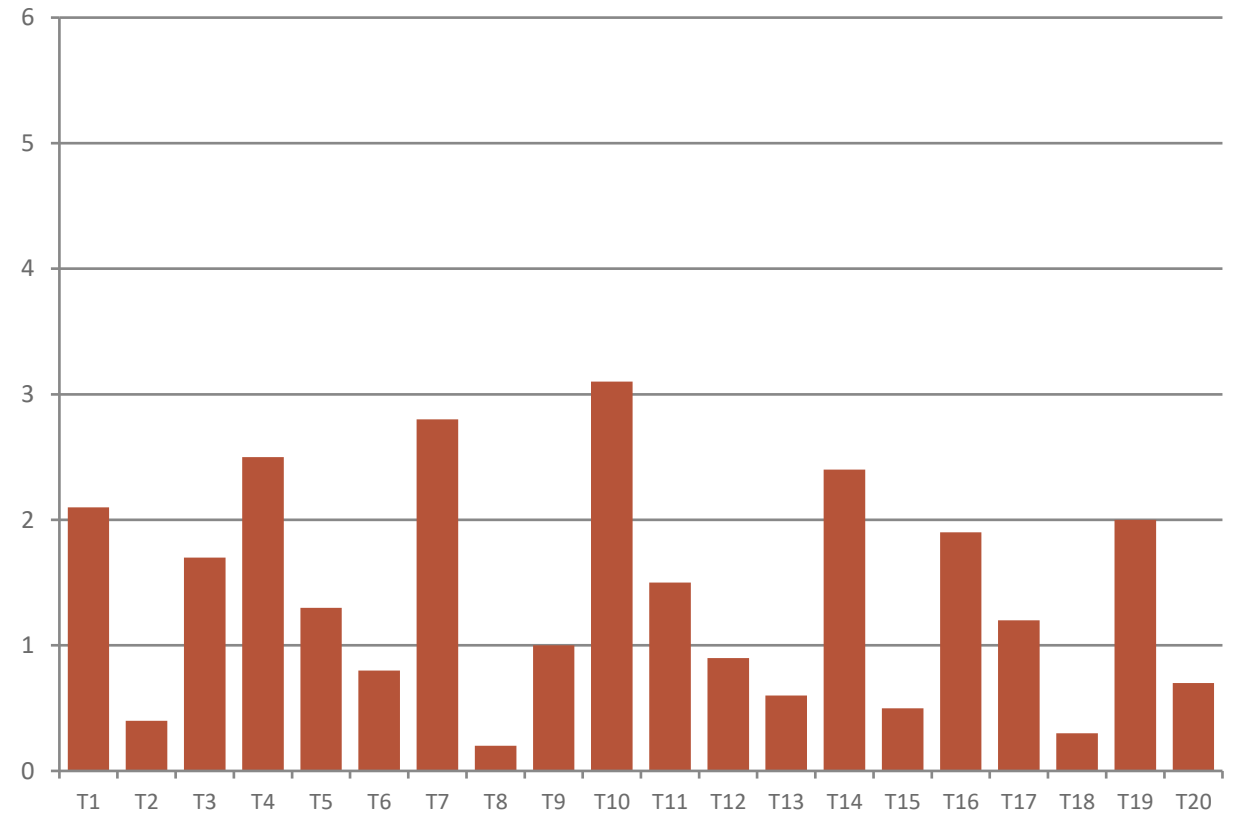
Conveyor positioning must be within ± 5 mm of each dispensing station across 20 trials.

VERIFICATION

Command the bowl to each dispensing station in turn. Measure the absolute distance between commanded and actual stop position with calipers. Repeat 20 times. All trials must be within 5 mm.

PASS max |error| 3.1 mm < 5 mm

Bowl position difference per station (20 trials)



max |diff| = 3.1 mm · mean |diff| = 1.34 mm · all within 5 mm tolerance

LCD: menu state transitions

REQUIREMENT

Menu state transitions must correctly change display states \geq 95 % of 50 test presses.

VERIFICATION

Press the recipe-select button 50 times in sequence. The LCD must update to the correct menu state at least 95 % of the time. Record any presses that fail to register or display the wrong state.

Menu state transitions across 50 button presses



98 %

Transition accuracy

1

Missed press (debounce hiccup)

PASS 49 / 50 · 98 %

1 missed press across 50 consecutive trials · exceeds 95 % requirement

Issues we faced



Conveyor rollers broke

The 3D-printed roller bearings cracked under repeated load and let the belt sled wobble side-to-side. We compensated by tightening the belt and slowing acceleration, which kept positioning within tolerance, but cost us travel speed.



Load cell warm-up drift

First few minutes after power-on, the HX711 baseline crept by ~ 3 g as the strain-gauge reached thermal equilibrium. We added an automatic re-tare before each recipe which clears the issue without any user action.



Menu debounce edge case

One out of 50 button presses registered as two events when held just past the 20 ms loop tick. Extended the falling-edge guard window, and it passes consistently in subsequent runs.

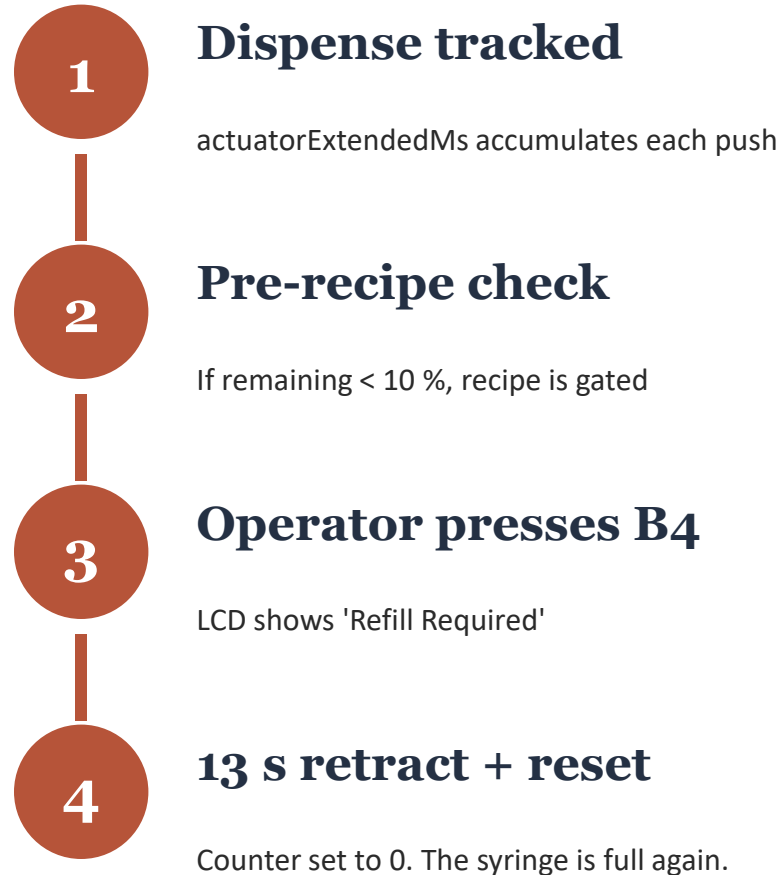
One-button syringe auto-refill

How it works

The firmware tracks cumulative actuator extension every dispense. Once the syringe drops below 10 % capacity, the next recipe halts and prompts the operator. A single press of B4 retracts the actuator for 13 s, which pulls the syringe back to its full position and resets the extension counter to zero.

Why it matters

- No mid-recipe failures: the dispense loop won't start unless there's enough fluid to finish.
- No mechanical disassembly to refill. The syringe stays in place. Only the sauce reservoir is topped off.
- Single-step UX. The operator gets a clear LCD prompt and one button to press.



CONCLUSIONS

What we learned



Closed-loop beats open-loop, every time

Volumetric dispense (push-weigh-repeat) was simpler to tune and more accurate than any time-based estimate. Trust the sensor, not the model.



Mechanical tolerances dominate everything

The biggest variability in dispense accuracy came from belt slack and roller wobble, not the firmware. Spend the time on the mechanism.



Understanding Strength

It is always important to understand what the key parts of the project are before assembly. Also, it is important to understand the strengths of everyone in the group.

WHAT'S NEXT

Future work & ethics

FUTURE WORK

1

Bring the funnel closer to the bowl

The gap between the funnel exit and the bowl rim caused occasional spillage on solid stations. A guided cylinder that drops the food directly into the bowl rim would eliminate it entirely.

2

Replace 3D-printed rollers with metal bearings

The original print failed under repeated load. Stainless ball bearings would restore the top-end conveyor speed and remove the lateral wobble that contributed to position error.

3

Auto-refill without admin interaction

Today the operator has to press B4 to refill the syringe. A pump from a storage system, plus a level sensor on the syringe, would make the system fully unattended.

ETHICS & SAFETY

Considerations for deployment

Food safety

Wood frame and exposed wiring are prototype-only. Production deployment requires food-grade stainless surfaces, sealed cable runs, and easy disassembly for daily cleaning.

Worker displacement

Per IEEE Code of Ethics §I.1, automation should augment workers, not eliminate them. Our framing centers freeing staff for higher-value tasks (quality, customer service), not headcount reduction.

Allergen integrity

Shared servos & funnels mean cross-contact risk. A production system would dedicate one funnel per allergen group and add a verifiable cleaning cycle.

Worker Safety

Ensure that there is an emergency stop button just in case anything goes wrong.

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Thank you.

Questions?